Fault-Tolerant Heat Exchanger

A single-point leak would not cause mixing of heat-transfer fluids.

Lyndon B. Johnson Space Center, Houston, Texas

A compact, lightweight heat exchanger has been designed to be fault-tolerant in the sense that a single-point leak would not cause mixing of heat-transfer fluids. This particular heat exchanger is intended to be part of the temperature-regulation system for habitable modules of the International Space Station and to function with water and ammonia as the heat-transfer fluids. The basic fault-tolerant design is adaptable to other heat-transfer fluids and heat exchangers for applications in which mixing of heat-transfer fluids would pose toxic, explosive, or other hazards: Examples could include fuel/air heat exchangers for thermal management on aircraft, process heat exchangers in the cryogenic industry, and heat exchangers used in chemical processing.

The reason this heat exchanger can tolerate a single-point leak is that the heat-transfer fluids are everywhere separated by a vented volume and at least two seals. The combination of fault tolerance, compactness, and light weight is implemented in a unique heat-exchanger core configuration: Each fluid passage is entirely surrounded by a vented region bridged by solid structures through which heat is conducted between the fluids. Precise, proprietary fabrication techniques make it possible to manufacture the vented regions and heat-conducting structures with very small dimensions to obtain a very large coefficient of heat transfer between the two fluids. A large heat-transfer coefficient favors compact design by making it possible to use a relatively small core for a given heat-transfer rate.

Characteristic		Non-Fault-Tolerant Design	Fault-Tolerant Design
Heat-Transfer Load	Design Point	14 kW	14 kW
	Pinch Point	25 kW	25 kW
Volume and Dimensions to Satisfy Pinch-Point Criterion		6.55 L 6.4 by 20.8 by 49.5 cm	2.5 L 9.1 by 12.7 by 21.6 cm
Mass (for Pinch-Point Criterion)		<12 kg	14.6 kg
Mass-Specific Heat Transfer	Design Point	>1.2 kW/kg	0.96 kW/kg
	Pinch Point	>2 kW/kg	1.7 kW/kg
Pressure	Maximum Allowable Working	3.7 MPa	3.7 MPa
	Proof	5.6 MPa	5.6 MPa
	Design/Burst	11.2 MPa	22.4 MPa
Pressure Drop on Primary (H_2O) Side at Mass Flow Rate of 380 g/s		19 kPa	19 kPa
Pressure Drop on Secondary (NH_3) Side at Flow Rate of 440 g/s		44.2 kPa	44.2 kPa

Design and Performance Characteristics of the fault-tolerant heat exchanger are shown alongside those of the prior non-fault-tolerant heat exchanger.

Calculations and experiments have shown that in most respects, the fault-tolerant heat exchanger can be expected to equal or exceed the performance of the non-fault-tolerant heat exchanger that it is intended to supplant (see table). The only significant disadvantages are a slight weight penalty and a small decrease in the mass-specific heat transfer.

This work was done by Michael G. Izenson and Christopher J. Crowley of Creare, Inc., for **Johnson Space Center**. *For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.*
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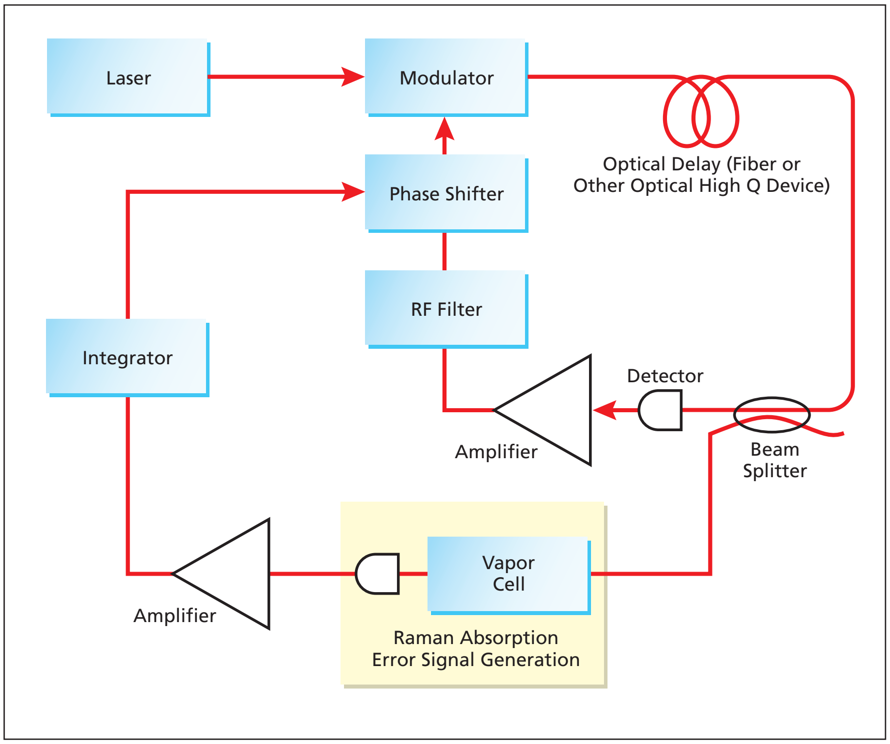
Atomic Clock Based on Opto-Electronic Oscillator

This apparatus would afford spectral purity plus long-term stability and accuracy.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed highly accurate clock or oscillator would be based on the concept of an opto-electronic oscillator (OEO) stabilized to an atomic transition. Opto-electronic oscillators, which have been described in a number of prior *NASA Tech Briefs* articles, generate signals at frequencies in the gigahertz range characterized by high spectral purity but not by long-term stability or accuracy. On the other hand, the signals generated by previously developed atomic clocks are characterized by long-term stability and accuracy but not by spectral purity. The proposed atomic clock would provide high spectral purity plus long-term stability and accuracy — a combination of characteristics needed to realize advanced developments in communications and navigation. In addition, it should be possible to miniaturize the proposed atomic clock.

When a laser beam is modulated by a microwave signal and applied to a photodetector, the electrical output of the photodetector includes a component at the microwave frequency. In atomic clocks of a type known as Raman clocks or coherent-population-trapping (CPT) clocks, microwave outputs are obtained from laser beams modulated, in each



This **Atomic Clock** would incorporate a conventional atomic clock and an opto-electronic oscillator in such a manner as to exploit the best features of both.

case, to create two sidebands that differ in frequency by the amount of a hyperfine transition in the ground state of atoms of an element in vapor form in a cell. The combination of these sidebands produces a transparency in the population of a higher electronic level that can be reached from either of the two ground-state hyperfine levels by absorption of a photon. The beam is transmitted through the vapor to a photodetector. The components of light scattered or transmitted by the atoms in the two hyperfine levels mix in the photodetector and thereby give rise to a signal at the hyperfine-transition frequency.

The proposed atomic clock would include an OEO and a rubidium- or cesium-vapor cell operating in the CPT/Raman regime (see figure). In the OEO portion of this atomic clock, as in a typical prior OEO, a laser beam would pass through an electro-optical modulator, the modulated beam would be fed into a fiber-optic delay line, and the delayed beam would be fed to a photodetector. The electrical output of the photodetector would be detected, amplified, filtered, and fed back to the microwave input port of the modulator.

The laser would be chosen to have the same wavelength as that of the pertinent ground-state/higher-state transition of the atoms in the vapor. The modulator/filter combination would be designed to operate at the microwave frequency of the hyperfine transition. Part of the laser beam would be tapped from the fiber-optic loop of the OEO and introduced into the vapor cell. After passing through the cell, this portion of the beam would be detected differentially with a tapped portion of the fiber-optically-delayed beam. The electrical output of the photodetector would be amplified and filtered in a loop that would control a DC bias applied to the modulator. In this manner, the long-term stability and accuracy of the atomic transition would be transferred to the OEO.

This work was done by Lute Maleki and Nan Yu of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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Microfocus/Polycapillary-Optic Crystallographic X-Ray System

This system generates an intense, nearly collimated beam suitable for crystallography.

Marshall Space Flight Center, Alabama

A system that generates an intense, nearly collimated, nearly monochromatic, small-diameter x-ray beam has been developed for use in macromolecular crystallography. A conventional x-ray system for macromolecular crystallography includes a rotating-anode x-ray source, which is massive (≥500 kg), large (approximately 2 by 2 by 1 m), and power-hungry (between 2 and 18 kW). In contrast, the present system generates a beam of the required brightness from a microfocus source, which is small and light enough to be mounted on a laboratory bench, and operates at a power level of only tens of watts.

The figure schematically depicts the system as configured for observing x-ray diffraction from a macromolecular crystal. In addition to the microfocus x-ray source, the system includes a polycapillary optic — a monolithic block (typically a bundle of fused glass tubes) that contains thousands of straight or gently curved capillary channels, along which x-rays propagate with multiple reflections. This particular polycapillary optic is configured to act as a collimator; the x-ray beam that emerges from its output face consists of quasi-parallel subbeams with a small angular divergence and a diameter comparable to the size of a crystal to be studied. The gap between the microfocus x-ray source and the input face of the polycapillary optic is chosen consistently with the focal length of the polycapillary optic and the need to maximize the solid angle subtended by the optic in order to maxi-